



U.S. ARMY TANK AUTOMOTIVE RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

# Blast Mitigation Seat Analysis – Assessment of the Effect of Personal Protective Equipment on the 5<sup>th</sup> Percentile Female Anthropomorphic Test Devices Performance in Drop Tower Evaluations

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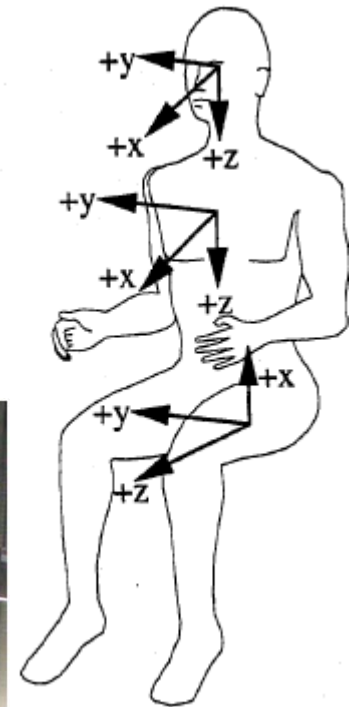
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# Testing Background



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- Baseline drop tower data collected from Anthropomorphic Test Devices (ATDs) seated in 12 models of Commercial Off-The-Shelf (COTS) and prototype blast energy-attenuating (EA) seats in various phases of engineering design development
- ATD data quality-checked and preliminary comparisons conducted
- Testing completed with:
  - 5<sup>th</sup> percentile Female ATDs
  - With or without personal protective equipment (PPE)
  - 200 g or 350 g pulse
- ATD injury assessment values compared to Occupant Centric Protection (OCP) Injury Assessment Reference Values (IARVs)
- ATD data channels recorded includes:
  - Accelerations
    - Head (Resultant, HIC15, HIC36)
    - Chest (Resultant)
    - Pelvis (DRI)
  - Forces/Moments
    - Upper Neck
    - Lumbar
    - Femur
    - Upper Tibia
    - Lower Tibia



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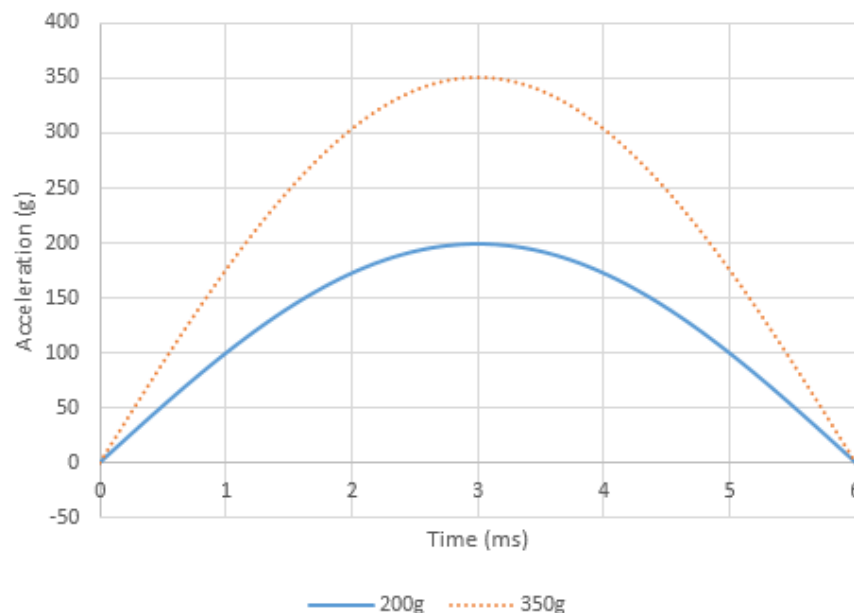


# Testing Background



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- Drop tower located at TARDEC Occupant Protection (OP) Laboratory
- Testing simulated the initial vertical loading event during an underbody blast
- Pulse profile variables include:
  - Maximum acceleration
  - Time to peak
  - Delta velocity
- Pulse profile tuning is achieved by changing:
  - Drop height
  - Platform payload
  - Energy absorbing medium
- Test matrix designed to maximize information gained
  - Focus of this study is to address the lack of knowledge of the effects of PPE on the 5<sup>th</sup> percentile female ATD



	200 g		350 g		Total
	PPE	No PPE	PPE	No PPE	
A	1	1	1	1	4
B	2				2
C			2	2	4
D	2	2	2	2	8
E	1		1		2
F		4		2	6
G	2	2	2	2	8
H	2	2			4
I	2	2			4
J	2	2		1	5
K	1	1			2
L			6		6
<b>Total</b>	<b>15</b>	<b>16</b>	<b>14</b>	<b>10</b>	<b>55</b>

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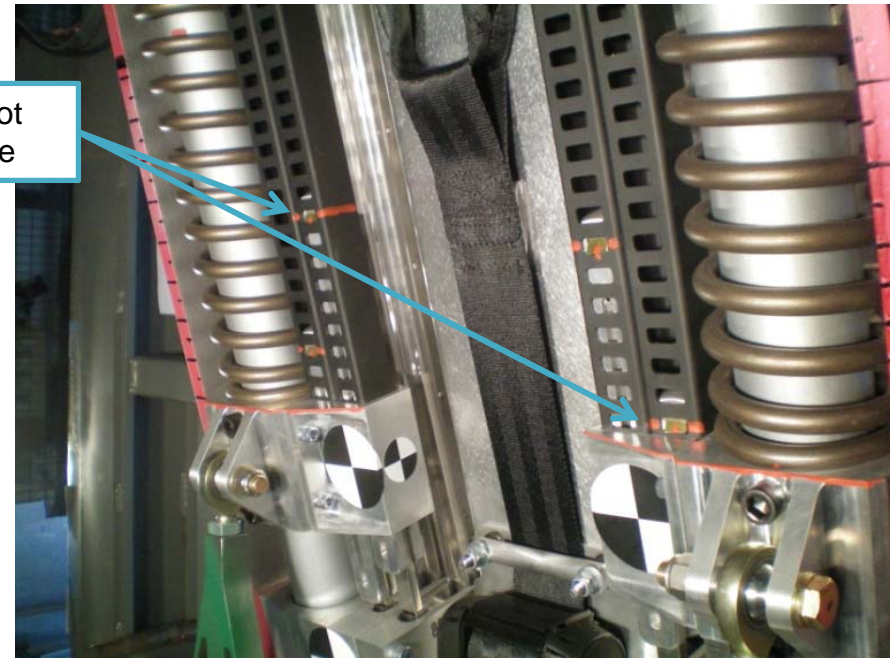
# Data Caveats



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- Caution should be used in directly comparing test results to each other based on differences in:
  - Test setup (ATD positioning, reusing seats)
  - Energy absorption devices
  - Suitability of each seat based on occupant size and impulse
- Seats were reused in multiple tests, so some seats experienced issues that may have affected results
  - Energy absorption malfunctions
  - Deformation to seat frames
- Limited data sets pose challenges in drawing concrete conclusions such as the effects of PPE
- Lab HVAC temperature was variable; unknown effects on data
- Impact velocity not recorded
- Rebound of platform resulted in higher delta velocity than impact velocity
- All caveats have not yet been identified

Did not  
stroke

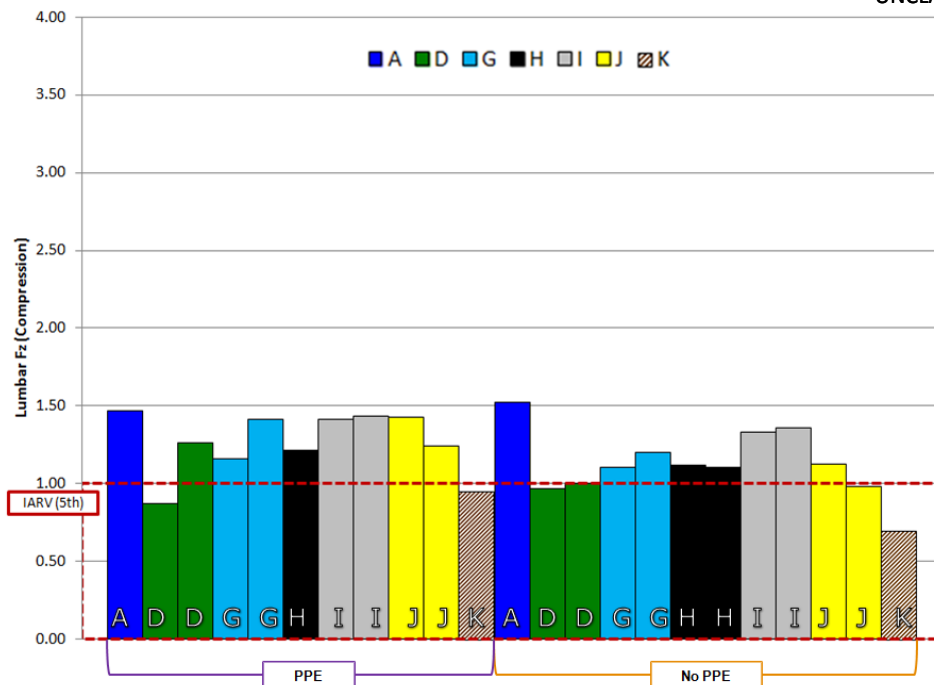


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# Lumbar FZ Compression Normalized – 200 g



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- Data normalized against 5<sup>th</sup> percentile female ATD OCP IARVs
- Addition of PPE at 200 g for all but one seat model caused an increase in lumbar compression

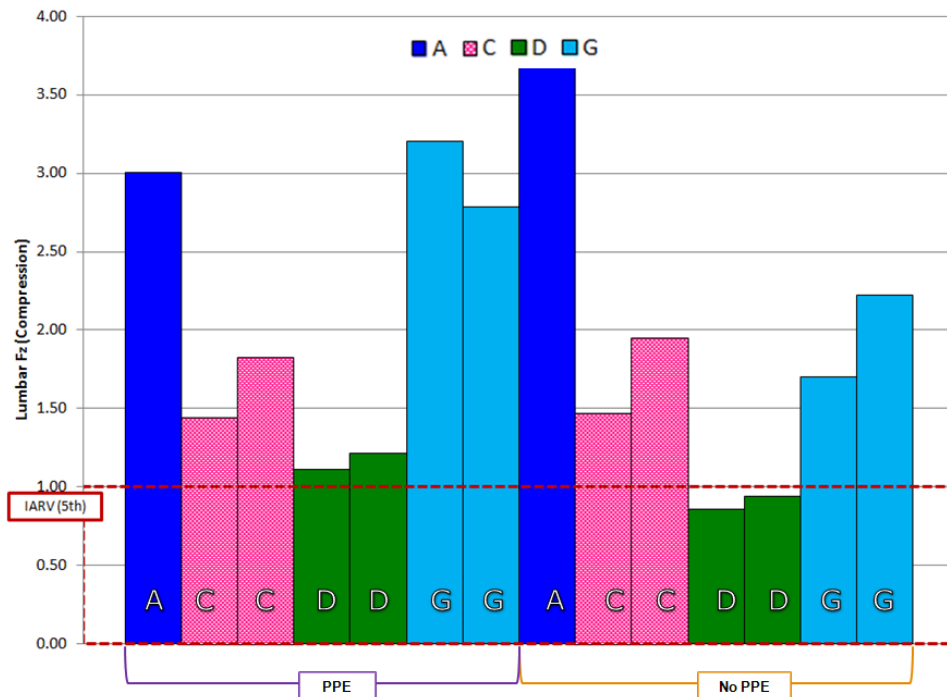
Seat ID	Test Number	Configuration	Lumbar Peak Compression Load [Normalized]	Change in Lumbar Peak Compression Load due to PPE
A	3	PPE	1.47	-4%
A	5	No PPE	1.53	
D	8	PPE	0.87	+8%
D	9	PPE	1.26	
D	4	No PPE	0.97	
D	5	No PPE	1.01	
G	5	PPE	1.16	+12%
G	6	PPE	1.41	
G	1	No PPE	1.10	
G	2	No PPE	1.20	
H	3	PPE	1.21	+9%
H	5	No PPE	1.12	
H	6	No PPE	1.10	
I	3	PPE	1.42	+6%
I	4	PPE	1.43	
I	5	No PPE	1.33	
I	6	No PPE	1.36	
J	4	PPE	1.43	+27%
J	5	PPE	1.24	
J	1	No PPE	1.12	
J	2	No PPE	0.98	
K	2	PPE	0.95	+36%
K	1	No PPE	0.70	

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# Lumbar FZ Compression Normalized – 350 g



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- Half of the seats tested resulted in increases of 30% to 52% in lumbar compression load
- Other two seats evaluated produced decreases of lumbar compression of -4% and -22%

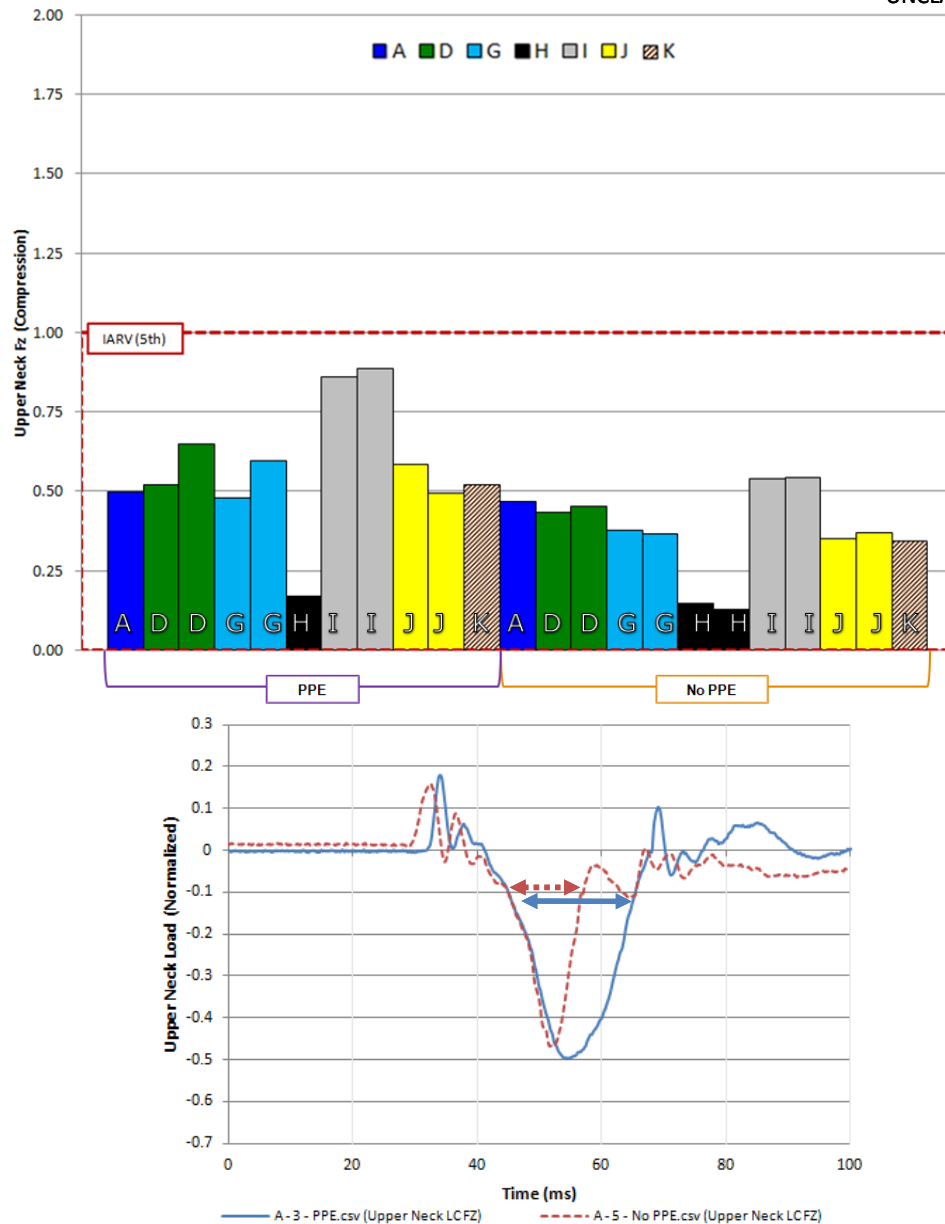
Seat ID	Test Number	Configuration	Lumbar Peak Compression Load [Normalized]	Change in Lumbar Peak Compression Load due to PPE
A	13	PPE	3.00	-22%
A	15	No PPE	3.86	
C	7	PPE	1.44	-4%
C	8	PPE	1.83	
C	9	No PPE	1.47	
C	10	No PPE	1.95	+30%
D	10	PPE	1.11	
D	11	PPE	1.22	
D	6	No PPE	0.86	
D	7	No PPE	0.94	+52%
G	7	PPE	3.20	
G	7a	PPE	2.78	
G	3	No PPE	1.70	
G	4	No PPE	2.23	

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# Upper Neck FZ Compression Normalized – 200 g



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Seat ID	Test Number	Configuration	Upper Neck Fz Peak Compression [Normalized]	Change in Upper Neck Peak Compression due to PPE
A	3	PPE	0.50	+7%
A	5	No PPE	0.47	
D	8	PPE	0.52	+32%
D	9	PPE	0.65	
D	4	No PPE	0.43	
D	5	No PPE	0.45	+47%
G	5	PPE	0.48	
G	6	PPE	0.60	
G	1	No PPE	--	+44%
G	2	No PPE	0.37	
H	3	PPE	0.65	+61%
H	5	No PPE	0.47	
H	6	No PPE	0.44	
I	3	PPE	0.86	+50%
I	4	PPE	0.89	
I	5	No PPE	0.54	
I	6	No PPE	0.54	+51%
J	4	PPE	0.58	
J	5	PPE	0.50	
J	1	No PPE	0.35	
J	2	No PPE	0.37	
K	2	PPE	0.52	
K	1	No PPE	0.34	

- ACH (helmet) adds more than 50% to weight sustained by ATD above upper neck load cell
- Addition of the helmet at the lower drop height resulted in increases ranging from 7% to 61% across seat models
- ACH weight (blue curve) tends to increase the duration of the load sustained by the upper neck due to mass recruitment effects

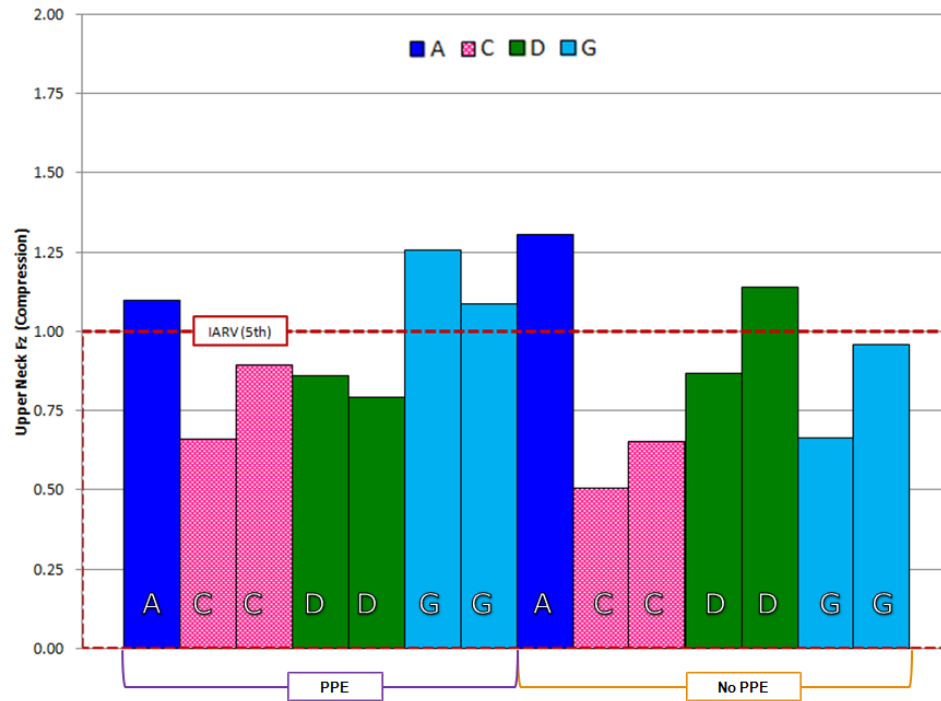
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# Upper Neck FZ Compression Normalized – 350 g

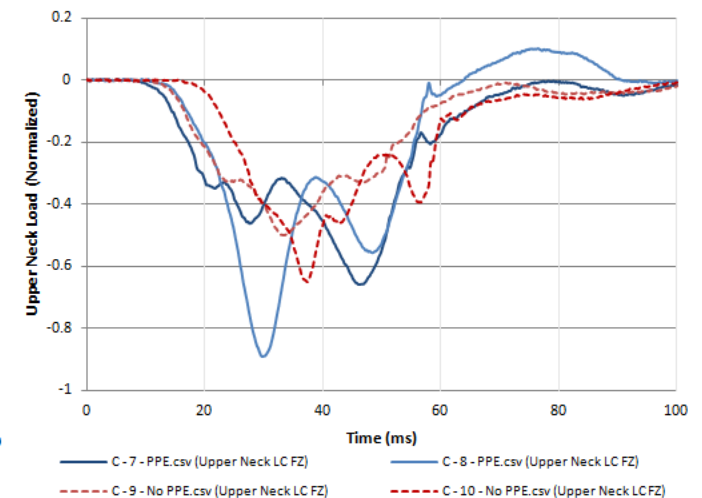
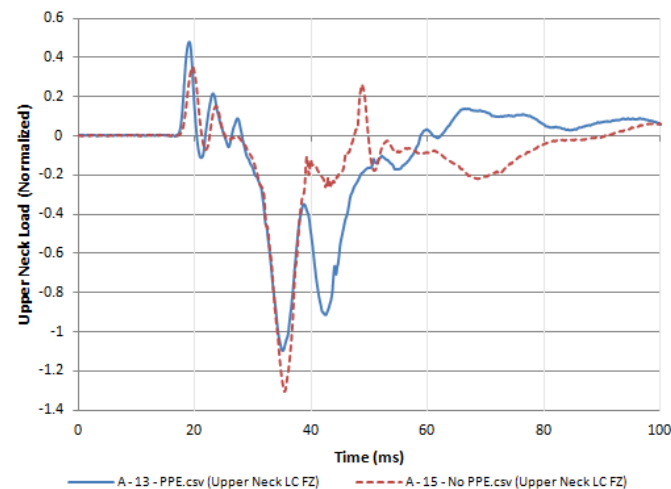


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Seat ID	Test Number	Configuration	Upper Neck Fz Peak Compression [N]	Change in Upper Neck Peak Compression due to PPE
A	13	PPE	1.10	-16%
A	15	No PPE	1.30	
C	7	PPE	0.66	+35%
C	8	PPE	0.89	
C	9	No PPE	0.50	
C	10	No PPE	0.65	
D	10	PPE	0.86	-18%
D	11	PPE	0.79	
D	6	No PPE	0.87	
D	7	No PPE	1.14	
G	7	PPE	1.26	+45%
G	7a	PPE	1.09	
G	3	No PPE	0.66	
G	4	No PPE	0.96	

- Half of the seats tested at 350 g resulted in increases of in upper neck compression load, similar to lumbar
- Trends in loading duration are not as consistent at 350 g with addition of PPE (blue)

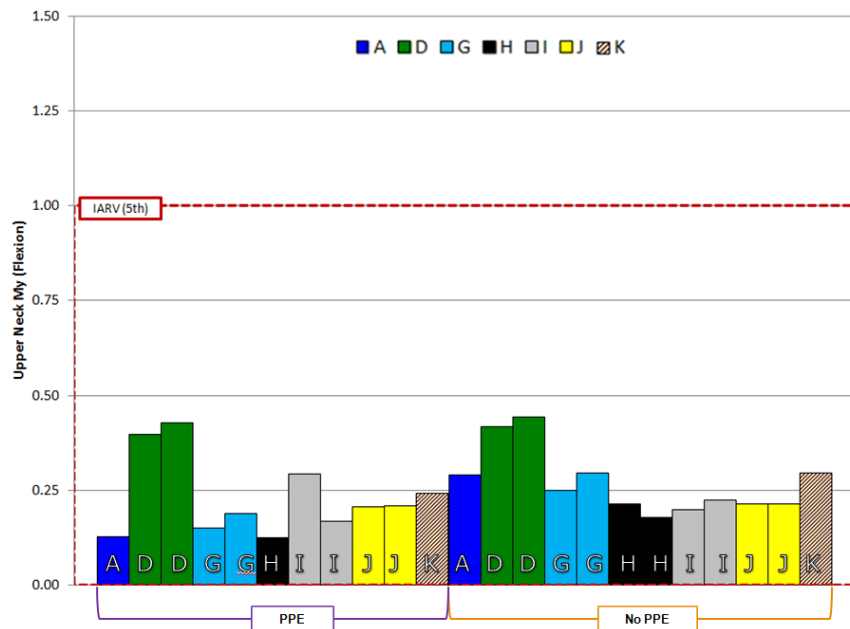


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# Upper Neck Moments Normalized – 200 g



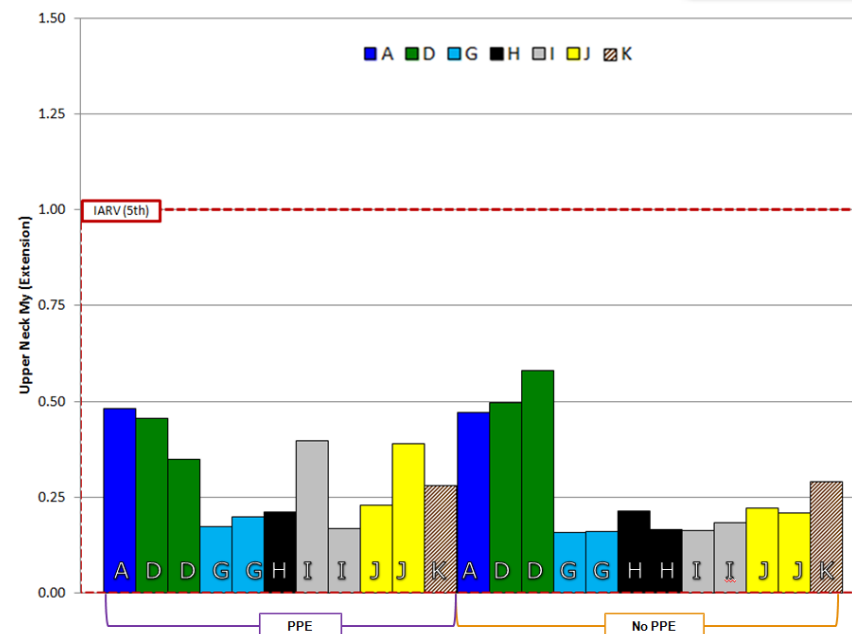
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Seat ID	Test Number	Configuration	Upper Neck Peak Flexion [Normalized]	Change in Upper Neck Peak Flexion due to PPE
A	3	PPE	0.13	-56%
A	5	No PPE	0.29	
D	8	PPE	0.40	-4%
D	9	PPE	0.43	
D	4	No PPE	0.42	
D	5	No PPE	0.44	
G	5	PPE	0.15	-38%
G	6	PPE	0.19	
G	1	No PPE	0.25	
G	2	No PPE	0.30	
H	3	PPE	0.12	-37%
H	5	No PPE	0.21	
H	6	No PPE	0.18	
I	3	PPE	0.29	
I	4	PPE	0.17	+9%
I	5	No PPE	0.20	
I	6	No PPE	0.22	
J	4	PPE	0.21	
J	5	PPE	0.21	-3%
J	1	No PPE	0.21	
J	2	No PPE	0.21	
K	2	PPE	0.24	
K	1	No PPE	0.29	-18%

•No definitive trends were noted in upper neck flexion or extension at 200 g  
•IARVs were not exceeded for any configuration

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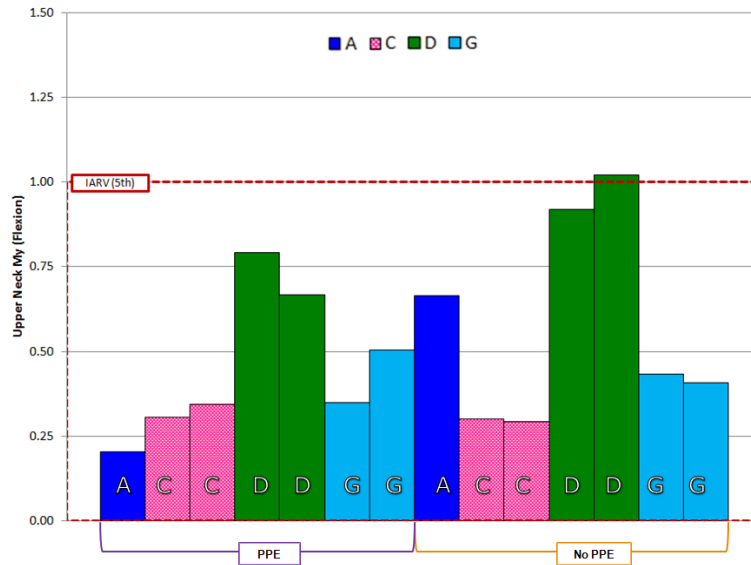


Seat ID	Test Number	Configuration	Upper Neck Peak Extension [Normalized]	Change in Upper Neck Peak Extension due to PPE
A	3	PPE	0.48	+2%
A	5	No PPE	0.47	
D	8	PPE	0.46	-25%
D	9	PPE	0.35	
D	4	No PPE	0.50	
D	5	No PPE	0.58	
G	5	PPE	0.17	+17%
G	6	PPE	0.20	
G	1	No PPE	0.16	
G	2	No PPE	0.16	
H	3	PPE	0.21	+10%
H	5	No PPE	0.22	
H	6	No PPE	0.17	
I	3	PPE	0.40	
I	4	PPE	0.17	+63%
I	5	No PPE	0.16	
I	6	No PPE	0.18	
J	4	PPE	0.23	
J	5	PPE	0.39	+44%
J	1	No PPE	0.22	
J	2	No PPE	0.21	
K	2	PPE	0.28	
K	1	No PPE	0.29	-4%

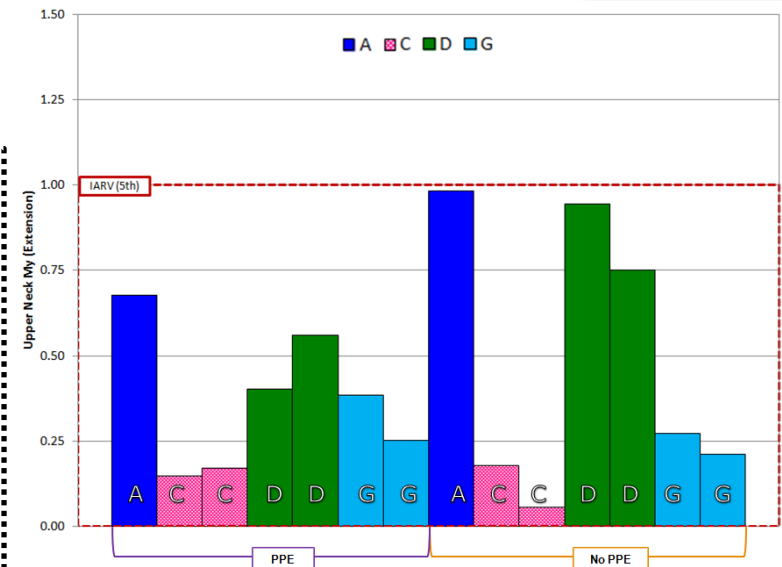
# Upper Neck Moments Normalized – 350 g



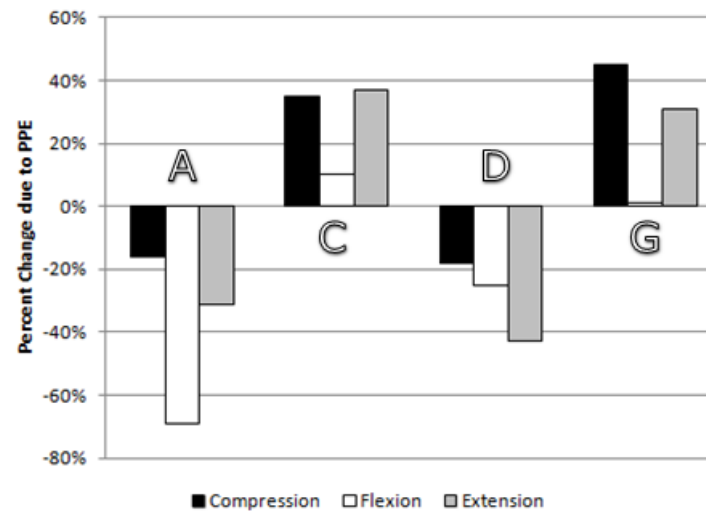
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•No definitive trends were noted in upper neck flexion or extension at 350 g  
•ACH effects on flexion and extension followed the same trends as compression at 350 g



Seat ID	Test Number	Configuration	Upper Neck Peak Flexion [Normalized]	Change in Upper Neck Peak Flexion due to PPE
A	13	PPE	0.20	-69%
A	15	No PPE	0.66	
C	7	PPE	0.30	+10%
C	8	PPE	0.34	
C	9	No PPE	0.30	-25%
C	10	No PPE	0.29	
D	10	PPE	0.79	-43%
D	11	PPE	0.67	
D	6	No PPE	0.92	+31%
D	7	No PPE	1.02	
G	7	PPE	0.35	+1%
G	7a	PPE	0.50	
G	3	No PPE	0.43	+1%
G	4	No PPE	0.41	



Seat ID	Test Number	Configuration	Upper Neck Peak Extension [Normalized]	Change in Upper Neck Peak Extension due to PPE
A	13	PPE	0.68	-31%
A	15	No PPE	0.98	
C	7	PPE	0.15	+37%
C	8	PPE	0.17	
C	9	No PPE	0.18	-43%
C	10	No PPE	0.05	
D	10	PPE	0.40	-43%
D	11	PPE	0.56	
D	6	No PPE	0.94	+31%
D	7	No PPE	0.75	
G	7	PPE	0.38	+31%
G	7a	PPE	0.25	
G	3	No PPE	0.27	+31%
G	4	No PPE	0.21	

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# Conclusions



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- The additional mass of PPE on the 5<sup>th</sup> percentile female is a contributing factor to injury outcomes during drop tower testing in EA seats
  - Advanced Combat Helmet (ACH) [+50% weight above upper neck load cell]
  - Improved Outer Tactical Vest (IOTV) [+55% weight of total ATD]
- Mass recruitment causes higher lumbar compression and upper neck compression forces
  - More pronounced in 200 g testing
  - Less consistent trends at 350 g
- No definitive trends for upper neck flexion or extension due to ACH weight
- The ballistic armor protection of the IOTV and ACH are critical to the safety of the soldier despite the potential for increased injury risk due to the additional weight
- The insight gained during this analysis may be useful for seat manufacturers, as future seat designs need to compensate for the effects of PPE during vertical accelerative loading event



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## Future Work/Next Steps



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- Further detailed analysis of the data is needed to fully comprehend the specific kinetic and kinematic effects of PPE on the small occupant.
- A more detailed timing analysis of the progression of forces and accelerations through the ATD could provide more insight into how the ATD interacts with the seat and PPE
- Future tests to evaluate the effect of PPE on the 5th percentile female ATD could include dynamic seat stroke characterization
- Drop tower data should be compared to live fire data to identify similarities and differences in ATD and seat response
- Further analysis of this data with respect to seat construction may allow an evaluation of seat characteristics to create an optimum seat design
- Repeating this same analysis on the 50<sup>th</sup> percentile male and 95<sup>th</sup> percentile male to determine if similar trends occur based on the effect of PPE on larger occupants
- Use lessons learned from data analysis to improve lab procedures and best practices
- Drop tower is currently being moved – lessons learned will be incorporated
- Future test plans can be developed to evaluate seats efficiently



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